environments, especially since many of these sites were in relatively pristine locations. The higher percentage of creek habitat with fair or poor conditions may also reflect, in part, the relatively greater effect of anthropogenic runoff into these smaller water bodies due to their proximity to upland sources and their lower dilution capacity.

Comparison of the state's overall water quality condition on an annual basis indicated very little change over the six years sampled by SCECAP to date (Figure 3.2.7). This is surprising since the state's estuarine habitat was altered considerably by increased rainfall in 2003 and 2004 based on the changes in the proportion of the state represented by the various salinity zones (Figure 3.2.1). For all years, about 80% or more of the state's estuarine waters rank as good in quality using the SCECAP criteria, and generally less than 5% of the estuarine waters ranked as poor in quality. We anticipated that the increased rainfall experienced during 2003-2004 might have an impact on the state's overall estuarine water quality, but the resulting data did not confirm this. Although some of the component parameters did show evidence of considerable change, the actual concentrations observed among the various sites sampled in a given year, combined with the mitigating effects of those parameters that did not show much change, are the probable reasons for a lack in major changes in the integrated water quality index.

3.3 Sediment Quality

Sediment Composition

The composition of marine sediments can affect the structure of benthic communities, the exchange rates of gases and nutrients between the water column and seafloor, and the bioavailability of nutrients and contaminants to resident fauna (Gray, 1974; Graf, 1992). In general, muddier sediments (those with more silt and clay) tend to host a different set of species, reduce the movement of gasses and nutrients, and retain more contaminants than sandier sediments.

During the 2003-2004 monitoring period, sediments in open water habitats were on average 19.6% silt/clay while sediments in tidal creek habitats were 30.4% silt/clay, a difference that was significant ($p = 0.013$). Within each habitat type, the percent silt/clay was highly variable, with open water stations varying from 0.7-94.7% and tidal creek stations varying from 2.0-97.8%. The sediments at one open water station (2.0%) and four tidal creek stations (7.0%) had greater than 80% silt/clay (Figure 3.3.1). These values are similar to previous study periods (Van Dolah *et al.,* 2002a, 2004a).

Sediment Total Organic Carbon

Total organic carbon (TOC) represents a measure of the amount of organic material present in sediments. At very low TOC levels, little food is available for consumers resulting in a low biomass community; at very high TOC levels, enhanced sediment respiration rates lead to oxygen depletion and accumulation of potentially toxic reduced chemicals. Hyland *et al*. (2000) found that TOC levels below 0.5 mg/g (0.05%) and above 30 mg/g (3.0%) were related to decreased benthic abundance and biomass.

The TOC content of open water sediments averaged 0.8% while tidal creek habitats averaged 1.2%, a difference that was significant ($p = 0.048$). The TOC of open water habitats varied from 0.03% to 5.5% and that of tidal creeks varied from 0.05% to 5.5%. Based on the criteria in Hyland *et al.* (2000), the sediments were impaired with respect to TOC at 20% of open water habitats (14% too low, 6% too high) and 15% of tidal creek habitats (3% too low, 12% too high; Figure 3.3.1). These values are similar to previous surveys (Van Dolah *et al.,* 2002a, 2004a). The tendency of open water habitats to be characterized by lower TOC levels than tidal creek habitats likely reflects their greater distance from terrestrial sources of organic material.

Porewater Ammonia

Total ammonious nitrogen (TAN) provides a measure of the concentration of ammonia, a highly reduced and potentially toxic form of nitrogen, in marine sediments. Sources of ammonia include terrestrial runoff, atmospheric deposition and bacterial activity (nitrate reduction and ammonification), many of which are increasingly impacted by human activities, resulting in greater nitrogen loads in coastal environments (Driscoll *et al.,* 2003).

The median porewater ammonia concentration was 1.9 mg/L in open water habitats and 2.1 mg/L

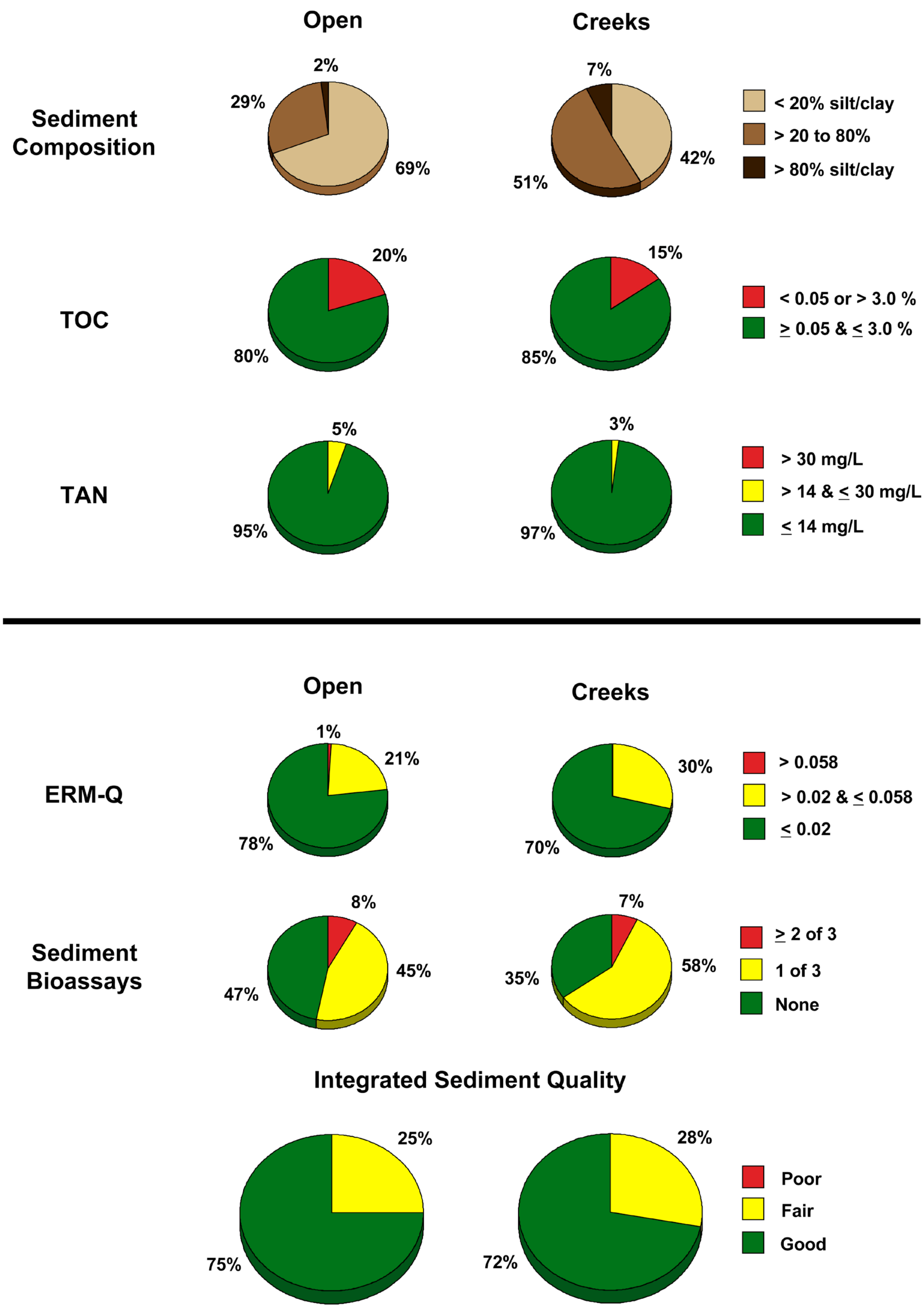
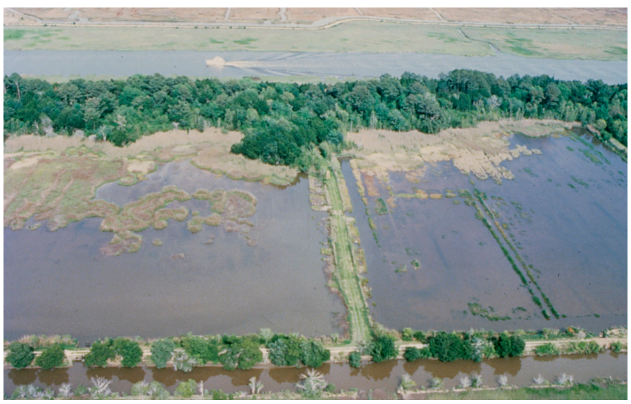


Figure 3.3.1. Comparison of the percent of the state's coastal habitat represented by various sediment quality conditions and integrated sediment quality scores.

in tidal creek habitats, a difference that was not significant. The TAN of open water habitats varied from 0.15 to 30.5 mg/L and that of tidal creeks varied from 0.1 to 25.3 mg/L. On average, less than half of one percent of South Carolina's open water or tidal creek habitat possessed ammonia concentrations characteristics of high stress habitats (Figure 3.3.1). A single station in open water had a TAN concentration of 30.5 mg/L but all remaining open water stations had TAN concentrations of less than 16 mg/L. The unusually high TAN concentration was found at station RO046076 near the confluence of Six Mile Creek and the Santee River. The area surrounding this station consists of extensive impoundments for waterfowl that may act as sources of nitrogen when water is released into the estuary during the late spring and summer.



The Santee River delta is highly impounded to attract waterfowl.

Contaminants

Contaminants enter coastal water bodies through direct release by users, runoff from terrestrial systems, and deposition from suspended material in the atmosphere. Common environmental contaminants include polycyclic aromatic hydrocarbons (PAHs; including compounds such as automobile oil), heavy metals (including mercury, chromium, etc), polychlorinated biphenyls (PCB's; including components of many flame retardants and electrical insulators manufactured before 1979) and pesticides (including DDT, etc.). Although SCECAP determined the levels of 160 contaminants in South Carolina's coastal waters, the consequences of many of these compounds to ecosystem function and human health remain uncertain.

Long and Morgan (1990) and Long *et al.* (1995, 1997) reviewed published toxicological studies involving 24 contaminants (all measured by SCECAP) and developed two metrics: Effects Range-Low (ER-L; concentration of a contaminant that resulted in adverse bioeffects in 10% of published studies) and Effects Range-Median (ER-M; concentration of a contaminant that resulted in adverse bioeffects in 50% of published studies). During the 2003-2004 monitoring period, 33 stations (including 12 open water and 21 tidal creek stations) had at least one contaminant that exceeded its published ER-L, and no station had a contaminant that exceeded its published ER-M. Four PAH's, the pesticide DDT, and 5 metals exceeded published ER-L (Table 3.3.1). The most widespread contaminant that exceeded its ER-L was arsenic. Arsenic accumulates in estuarine sediments as a result of the weathering of terrestrial rock, thus its presence in South Carolina's coastal sediments (particularly in tidal creeks) is likely a result of natural upland erosion. Disturbance of these sediments, such as may occur through slumping, erosion or dredging, however, can re-suspend buried arsenic (Saulnier and Mucci, 2000) making it available for uptake by estuarine fauna and increasing chances of contact with the human population.

To assess the overall bioeffect of the 24 contaminants with published guidelines, an Effects Range Median Quotient (ERM-Q) was calculated for each station. ERM-Q is calculated by dividing the measured concentration of each of the 24 contaminants by its ER-M values and then averaging the 24 values. Hyland *et al.* (1999) demonstrated that ERM-Q provides a reliable index of benthic stress in southeastern estuaries, with ERM-Q values ≤ 0.020 representing a low risk, values > 0.020 and ≤ 0.058 representing a moderate risk, and values > 0.058 representing a high risk of observing degraded benthic communities. The median ERM-Q of open water sediments was 0.010 and that of tidal creeks was 0.014, a difference that was not significant. ERM-Q varied from 0.001 to 0.076 in open water habitats and from 0.003 to 0.056 in tidal creek habitats. ERM-Q values were in the moderate risk range in 30% of the state's tidal creek habitat and 21% of the state's open water habitat and in the high risk range in 1% of the state's open water habitat (Figure 3.3.1). One open

Table 3.3.1. Contaminants that exceeded published ER-L. Also shown is the number of stations in each habitat type where this occurred.

Contaminant Type	Name	Number of Stations
PAH	Acenaphthene	2; RO036042, RO046071
	Anthracene	3; RO036042, RO036153, RT042067
	Fluorene	1; RO032032
	2-methylnapthalene	2; RO036044, RT042194
Pesticide	DDT	2; RO036044, RT042194
Metal	Arsenic	25; 8 open water, 17 tidal creek
	Cadmium	1; RO046073
	Copper	1; RO042070
	Lead	1; RT042193
	Nickel	7; RT032174, RT032188, RT046062, RT042070, RO046064, RO046076, RO046078

water station had an ERM-Q value within the high risk range: RO036042 in the Cooper River northeast of the mouth of Goose Creek (ERM-Q = 0.077). The Cooper River is extensively developed for industrial purposes, and the SCECAP station assessed here was situated near a U.S. Naval ammunition depot. This station was characterized by unusually high metal, PAH, PCB, and pesticide levels.

Coastal ERM-Q values have increased significantly since the start of SCECAP in 1999, particularly in open water habitats (P = 0.018; Table 3.3.2). Similarly, the percent of tidal creek and open water habitat in South Carolina having ERM-Q values indicative of moderate to high risk of contamination has increased consistently from 21% to 30% in tidal creek habitats and from 12% to 22% in open water habitats (Figure 3.3.2). A significant increase in metal concentrations (P < 0.0005) and increasing PAH contamination contributed most heavily to the increasing ERM-Q.

The Cooper River at Charleston is a busy shipping port and a heavily developed industrial area.

Table 3.3.2. Average ERM-Q values in open water and tidal creek habitats between 1999 and 2004. Averages were used rather than medians because only ERM-Q in developing and potentially polluted watersheds (a relatively small percent of SC coastal watersheds) would be expected to change over time, a response that would not be reflected by medians.

Habitat	1999	2000	2001	2002	2003	2004
Tidal Creek	0.0126	0.0131	0.0132	0.0171	0.0145	0.0152
Open Water	0.0148	0.0145	0.0175	0.0154	0.0180	0.0163

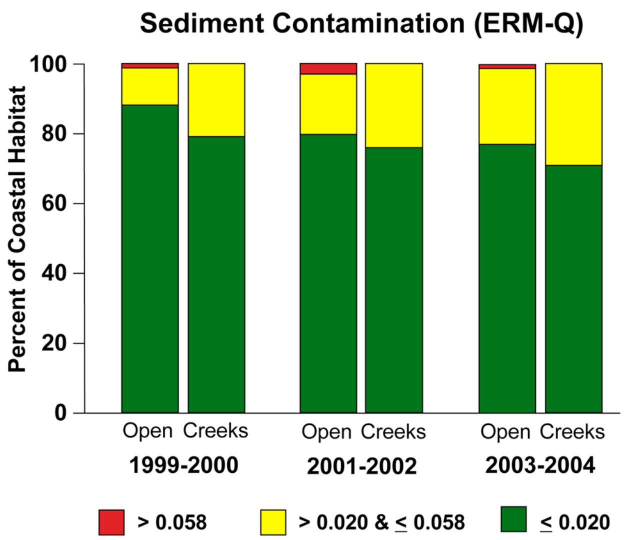


Figure 3.3.2. Change in ERM-Q in open water and tidal creek habitat since the start of SCECAP monitoring in 1999.

Toxicity Bioassays

Sediments may contain a wide range of contaminants, but the ability of those contaminants to negatively impact healthy biological communities depends on their availability to the resident fauna as well as interactive effects among the contaminants. Bioassays provide a means of determining the biological relevance of contaminant loads by examining the performance of living organisms in samples of native sediment (Ringwood and Keppler, 1998).

This SCECAP study applied three bioassays simultaneously—Microtox® bacterial growth, seed clam growth and amphipod survivorship—in order to provide a weight of evidence estimate of sediment toxicity to benthic fauna. Positive test results in at least two of the three assays indicates a high probability of toxic sediments, positive results in only one of the three assays indicates possible evidence of toxic sediments and no positive results indicates non-toxic sediments. Using these guidelines, 8% of the open water and 7% of the tidal creek habitat in South Carolina had a high probability of containing toxic sediments, and an additional 45% of open water and 58% of tidal creek habitat had evidence of possible toxicity (Figure 3.3.1).

Using the data available from all six years of SCECAP, we examined the ability of the bioassays to reflect ERM-Q scores. The number of assays showing positive results (excluding the amphipod assay) was significantly greater when ERM-Q scores were higher ($P < 0.0005$) indicating these assays provide a quantifiable estimation of sediment toxicity. While this describes a general tendency of the bioassays to detect toxicity at stations with higher contaminant loads, these bioassays did not entirely reflect contaminant levels. The amphipod assay produced only three positive results during the current study period, all at stations with good ERM-Q scores. This, combined with a general lack of amphipod toxicity in previous surveys, indicates that this assay does not perform well in this region. The Microtox® assay was very sensitive to stations with poor contaminant conditions (detected 100% of stations with high risk ERM-Q scores) but it displayed a tendency to generate many false positive results (detected toxic conditions at 41% of stations with good ERM-Q scores; Table 3.3.3). The clam assay was not as effective at detecting poor contaminant conditions (detected 43% of stations with high-risk ERM-Q

Table 3.3.3. Number of negative and positive Microtox® and seed clam bioassay results at stations with low, moderate and high risk ERM-Q scores. False positives are considered those assays with positive results at stations with a low-risk ERM-Q, and false negatives are considered those assays with negative results at stations with a high risk ERM-Q. By combining the Microtox and clam bioassays (combined columns), the ability to correctly detect low-risk (combined = 0), moderate-risk (combined = 1) and high-risk (combined = 2) improves.

	Microtox®		Clam		Combined		
ERM-Q	**-**	**+**	**-**	**+**	**0**	**1**	**2**
Low-risk	156	109	240	25	141	114	10
Moderate-risk	32	58	69	21	22	57	11
High-risk	0	7	4	3	0	4	3

scores), but it also did not generate a large number of false positive results (detected toxic conditions at 9% of stations with good ERM-Q scores; Table 3.3.3). Combining the Microtox® and clam bioassay to generate a score of 0 (positive in neither assay), 1 (positive in one assay), or 2 (positive in both assays) tends to decrease rates of false positive and false negative results. 53% of stations with good ERM-Q scored 0 in the combined assays, and 96% scored a 0 or 1. 43% of stations with poor ERM-Q scored as 2 in the combined assay and 100% scored as 1 or 2. Taken together, this supports coupling these bioassays in studies of sediment toxicity such that the Microtox® assay provides the ability to more consistently detect sites that have high sediment contaminant loads while the clam assay helps to limit the number of stations incorrectly identified as toxic by the Microtox® assay.

The "false positive" rate in the toxicity bioassays may reflect the effects of contaminants not incorporated into the ERM-Q or other environmental parameters. Most of the contaminants measured by SCECAP as well as many new unmeasured contaminants in the environment have no published bioeffects guidelines. For example, station RT042266 had unusually high concentrations of two PAH compounds considered to be carcinogenic, but these contaminants could not be incorporated into the ERM-Q due to lack of bioeffect guidelines. Environmental parameters other than sediment contaminants could also contribute to station toxicity. For example, while station RO046076 possessed an ERM-Q score indicative of fair conditions, both the Microtox® and clam bioassays indicated it was toxic; this station also possessed the lowest dissolved oxygen concentration of the current study period and the highest TAN value recorded in the six years of the SCECAP study.

Integrated Assessment of Sediment Quality

The integrated sediment quality index combines ERM-Q (a measure of total sediment contaminant levels) and sediment toxicity bioassays (a measure of the bioeffects of sediment contaminants). For SCECAP, an integrated sediment quality score of < 2 represents relatively poor sediment quality, scores ≥ 2 but < 4 represent fair sediment quality and scores ≥ 4 represent good sediment quality. During the 2003-2004 study period, 25% of open water and 28% of tidal creek habitat scored as fair while no habitat scored as poor (Figure 3.3.1). This suggests an improvement over the previous two study periods with the percent of habitat scored as good increasing from 72% to 75% in open water habitats and from 60% to 72% in tidal creek habitats (Figure 3.3.3). The large difference in the tidal creek habitats between study periods is due to an relatively small percentage (44%) of tidal creek stations receiving a good integrated sediment quality score in 2001. This same year had the highest proportion of false positive bioassay results (69%) in tidal creek habitats of any year. However, on a yearly basis, there has been no significant change in the integrated sediment quality scores of open water or tidal creek stations since the beginning of SCECAP monitoring (Fig 3.3.3).

The conflicting trends noted between the integrated sediment quality scores (which suggest improving or unchanging habitat quality) and ERM-Q (which suggest increasing contamination) likely reflect the averaging of ERM-Q and toxicity bioassay results in conjunction with a high rate of false positive and negative results among the bioassays. For example, the station with the highest ERM-Q during the current report period only scored as toxic in the Microtox® bioassay. Conversely, of the stations that scored as toxic in both the Microtox® and clam bioassays, 42% possessed low-risk ERM-Q values and only 13% possessed high-risk ERM-Q values. The result is that, once combined into an integrated score, these components average out to produce good or fair conditions at most stations. This stresses the importance of considering the individual components of the integrated scores (whether water quality, sediment quality or biological integrity) rather than relying solely upon the integrated scores for judging the state of our coastal waters.

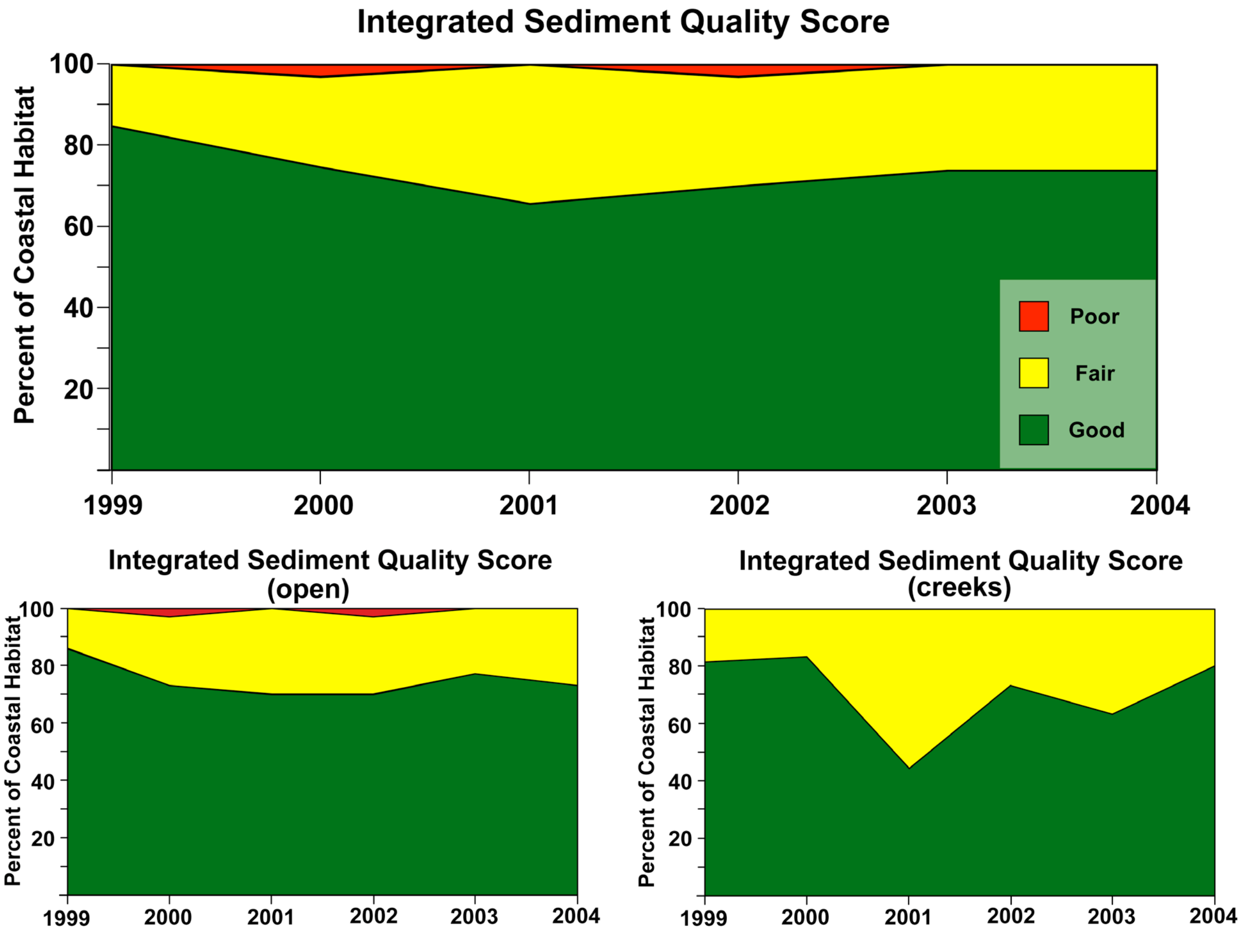


Figure 3.3.3. Proportion of the South Carolina's estuarine habitat that ranks as good (green), fair (yellow) or poor (red) using the integrated sediment quality score when tidal creek and open water habitats are combined and compared on an annual basis, and for tidal creek and open water habitats considered separately.

3.4 Biological Condition

Phytoplankton

Phytoplankton biomass and composition serve as valuable indicators of estuarine health because these primary producers respond rapidly to increases in nutrient loading. Even short-term increases in nutrient inputs can promote blooms of algal species that are often present but not overabundant in balanced, healthy estuarine systems. Increased nutrient inputs promote a complex set of environmental responses, beginning with shifts in algal composition and leading to blooms of harmful species that have deleterious impacts on biota (Bricker *et al.,* 1999). Harmful species are defined by the potential to produce blooms or toxins that have negative effects on biological systems (causing fish kills for example) and in some cases cause human health problems (such as paralytic shellfish poisoning).

Most harmful algal species fall within the cyanobacteria, dinoflagellate and raphidophyte groups, although not all species within these taxa are harmful and some may appear within the diverse assemblages of pristine estuarine systems. These

Fishkill in a stormwater detention pond caused by a toxic cyanobacterial bloom. Photo credit: SCAEL